The University of Chicago

FACTORS IN THE LEARNING BEHAVIOR OF THE ALBINO RAT

A PART OF A DISSERTATION SUBMITTED TO THE FACULTY OF THE DIVISION OF THE BIOLOGICAL SCIENCES IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY
1938

By

NEIL J. F. VAN STEENBERG

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SEPTEMBER, 1939

FACTORS IN THE LEARNING BEHAVIOR OF THE ALBINO RAT

NEIL J. F. VAN STEENBERG
From the Department of Psychology, The University of Chicago

The table of intercorrelations published by Dr. R. L. Thorndike in the *Genetic Psychology Monographs*, 1935, **17**, No. 1, has been reanalyzed into ten factors. Rotation of the reference vectors resulted in a configuration which, for all practical purposes, may be said to show a simple structure and (except for one variable on one factor) a positive manifold. Five of the factors can be interpreted with some confidence, one only with considerable caution; three factors are specific to the apparatus employed, and for the one remaining factor, no interpretation is attempted; it appears to be a residual plane.

For some years data obtained by experimentation on animal learning have been analyzed statistically. In the beginning of this period such investigators as Davis and Tolman (**3**) and others hoped to find a single most satisfactory criterion of learning, i.e., a criterion having the maximal reliability and validity. Later the assumption of a unitary learning factor was attacked and shown to be untenable and it was demonstrated that several unrelated factors were involved [e.g., Lashley (**13**), Leeper (**14**), Commins, McNemar and Stone (**2**)]. With reference to this complexity, Tomilin and Stone (**25**) wrote in 1934:

> We look upon this discovery as one of capital importance because now-a-days many problems in animal psychology are attacked by laboratory methods masquerading under the same name, but differing from each other in many essential details. So long as we lack accurate information as to the community of function of these diverse techniques of experimentation, just so long shall we continue to grope in the dark while seeking plausible explanations of the divergent results obtained on fundamental problems.

There is still another (though related) reason why learning, particularly animal learning, needs a thorough analysis. Traditionally, descriptions of such learning have confined themselves to terms involving laboratory apparatus employed; thus, we have maze behavior or rather behavior in particular mazes, and the relationship of this behavior to that on a puzzle box or to that shown on a delayed response apparatus. Such descriptions are, in the last analysis, chaotic and otherwise unsatisfactory. Experimentation is never-ending and predictions of future behavior of the animals in other situations are unreliable.

It is the purpose of this paper to investigate some measures of animal learning behavior and to isolate, if possible, the number of independent variables that must be dealt with in problems of this kind. For this purpose, attention was turned to a study by R. L. Thorndike which appeared in the *Genetic Psychology Monographs*, 1935, **17**, No. 1. It contained (among other items) a table of intercorrelations between scores on performances on a latch box, a number of mazes and other problems in learning. Thorndike had extracted three centroid factors from this table, but had stopped at this point because of a faulty criterion.* Furthermore, no attempt was made: (1) to determine whether a simple structure† would fit the configuration of vectors, or (2) to rotate the axes in any other manner. It was thought that considerably more information could be obtained from this table than had been extracted from it. Hence, a fresh attack was made on it to answer, if possible, such questions as:

1. Can animal behavior be parsimoniously described in terms of a limited number of abilities; i.e., can the above-mentioned table of intercorrelations of behavior measures be duplicated (allowing for small observational errors) by employing a substantially smaller number of factors than was made use of in the original composition of the table?

2. Will such abilities be found to be independent of one another; i.e., are the primary factors obtained orthogonal (uncorrelated)?

3. Do any of the abilities found render "good" performance (see page 182) on any of the tasks in question more difficult; that is, are any of these factor loadings negative, so that they cannot be enclosed within a positive manifold?

4. What are the verbal interpretations of the several abilities employed by the animals and methodologically isolated?

Partial Résumé of Thorndike's Report. In order that the reader may understand the results of the present investigation from this report, I shall give a résumé of the relevant material from Thorndike's report.

There are thirty-two variables representing different kinds of scores. They are presented in the temporal order of performance of the various tasks.

* The criterion was that the residuals from the whole table should form a distribution which approximated normality and should have for a standard deviation the standard error of the correlation coefficient derived on the assumption that the true correlation between the variables is zero.

† By simple structure is meant a selection of defining axes which maximizes the number of vanishing factor loadings, i.e., maximizes the number of zero entries in matrix F_f.

(1) Number of turns made on a revolving wheel activity cage.

Warner-Warden Mazes, *A* and *B* (alley mazes).

Maze *A* (see sketch, Plate I. Adapted from Thorndike's article, p. 24).

(2) "*A* errors" — entering a blind alley while progressing toward a goal box.
(3) "*B* errors" — entering a blind alley while proceeding in the reverse direction.
(4) "*C* errors" — retracing the true pathway.
(5) Total time (from entrance box to goal box).

Maze *B* (see sketch, Plate I).

(6) "*A* errors."
(7) "*B* errors."
(8) "*C* errors."
(9) Total time.

Elevated Mazes *C* and *D*.

Maze *C* (see sketch, Plate I).

(10) "*A* errors."
(11) "*B* errors."
(12) "*C* errors."
(13) Time to start running.
(14) Time to run.

Maze *D* (see sketch, Plate I).

(15) "*A* errors."
(16) "*B* errors."
(17) "*C* errors."
(18) Time to start running.
(19) Time to run.

Jenkins Circular Problem Box (see sketch, Plate I. Adapted from F. L. Riess, Limits of learning in the white rat and the guinea pig, *Genet. Psychol. Monog.*, 1934, **15**, p. 313).

(20) Number of quadrants entered before reaching food compartment door sprung by stepping on floor plates.
(21) Perfect trials (a more or less subjective estimate of the excellence of the animal's performance).
(22) Time to start from entrance box.
(23) Time to run.

Latch Box Problem (see sketch, Plate I).

(24) Time to reach food compartment.

Conditioned Response (see sketch, Plate I. Adapted from L. N. Warner, Association span of the white rat, *J. Genet. Psychol.*, 1932, **41**, p. 64).

Animal required to jump across a fence to avoid shock which follows ten seconds after a stimulus, which, in variables [25] and [26], was a buzzer.

(25) Score — number of crossings (of fence) following buzzer.

(26) Number of crossings in the intervals between trials.

(27) Same as twenty-five except a light was substituted as the conditioned stimulus.

(28) Number of crossings in the intervals between trials.

Columbia Obstruction Apparatus (see sketch, Plate I. Adapted from T. R. Jenkins, L. N. Warner, and C. J. Warden, Standard apparatus for the study of animal motivation, *J. Comp. Psychol.*, 1926, **6**, p. 366).

Animal motivated by one-day hunger was required to cross electric grid to reach food compartment.

(29) Number of approaches to the grid.

(30) Number of contacts with the grid (resulting in shock).

(31) Number of complete crossings of the grid.

Feeding on Preliminaries.

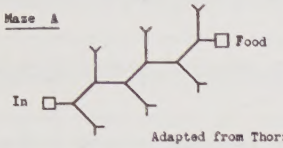
(32) The ratio of the time actually spent in eating to the total time available for this purpose, obtained on the preliminary training on Maze A, the Jenkins Box and the obstruction apparatus.

The scores of these variables were correlated and the direction of the variable chosen in such a manner as to call all "good" scores the same sign. Whatever a "good" score was to be was arbitrarily defined, and the following were chosen as "good" scores:

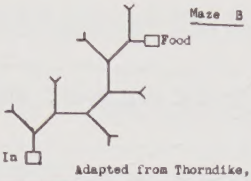
Revolving Wheel — large number of turns.
Mazes — few errors or short time.
Problem boxes — short time, few quadrants entered, and many perfect trials.
Conditioned Response — many crossings of the fence.
Columbia Obstruction Box — many approaches, contacts or crossings.

The upper right portion of Table I (above the diagonal) shows the matrix of raw intercorrelations obtained in this manner and found on pages 42 and 43 of Thorndike's monograph.

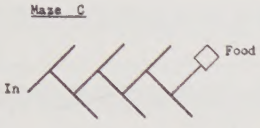
PLATE I.
FIG. 1.



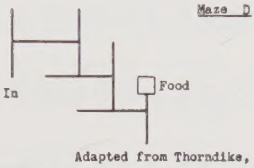
Adapted from Thorndike, R.L.



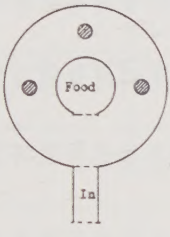
Adapted from Thorndike, R.L.



Adapted from Thorndike, R.L.

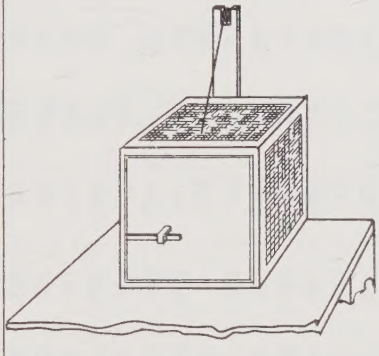


Adapted from Thorndike, R.L.



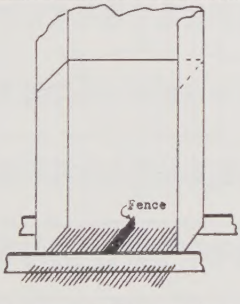
Jenkins' Problem Box

Adapted from Riess, F.L.



Latch Problem Box

Adapted from Thorndike, R.L.



Conditioned Response Test Apparatus

Adapted from Warner, L.H.

Columbia Obstruction Box

Adapted from Jenkins, T.N.,
Warner, L.H. and Warden, C.J.

TABLE I

Entries below the diagonal: the matrix R obtained by multiplying the factorial matrix F_c by F'_c;
Entries above the diagonal: the empirically obtained correlations as reported by Thorndike

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1		.27	.25	.23	.36	.13	.07	.12	.19	.26	.25	.23	.25	.25	.03	.06
2	.26		.79	.88	.82	.39	.43	.42	.29	.53	.32	.57	.46	.57	.32	.39
3	.25	.82		.87	.81	.36	.46	.42	.33	.56	.40	.61	.46	.56	.16	.37
4	.24	.87	.87		.84	.26	.47	.38	.28	.56	.34	.61	.48	.58	.14	.32
5	.29	.82	.81	.83		.29	.39	.36	.41	48.	.39	.61	.59	.69	.09	.26
6	.15	.36	.33	.27	.29		.74	.85	.74	.20	.04	.22	.11	.10	.34	.35
7	.10	.43	.49	.43	.38	.79		.91	.79	.18	—.04	.22	.18	.09	.26	.37
8	.11	.42	.43	.38	.37	.86	.91		.82	.13	—.03	.23	.13	.07	.19	.32
9	.17	.30	.32	.28	.39	.75	.78	.81		.12	—.01	.22	.27	.17	.15	.16
10	.26	.55	.56	.56	.48	.19	.19	.15	.09		.50	.72	.45	.58	.40	.26
11	.21	.34	.37	.35	.38	.05	—.03	—.05	.03	.58		.68	.53	.68	.40	.26
12	.27	.58	.60	.60	.62	.22	.21	.21	.20	.65	.68		.58	.81	.23	.18
13	.25	.44	.49	.49	.62	.13	.17	.13	.32	.43	.52	.62		.74	.12	.08
14	.27	.54	.57	.58	.69	.09	.10	,07	.20	.57	.67	.79	.74		.17	.07
15	.04	.27	.19	.18	.09	.33	.23	.21	.16	.40	.36	.32	.12	.19		.38
16	.06	.37	.40	.32	.26	.36	.35	.29	.16	.26	.17	.19	.04	.12	.40	
17	.04	.35	.35	.28	.20	.38	.36	.29	.17	.26	.15	.16	.01	.07	.50	.80
18	.23	.24	.25	.23	.39	.33	.33	.27	.58	.17	.23	.23	.49	.37	.20	.16
19	.16	.46	.41	.39	.38	.39	.33	.30	.29	.42	.37	.42	.30	.37	.51	.50
20	—.21	.12	.02	.02	.00	.22	.14	.18	.10	—.02	—.04	—.14	—.17	—.20	.17	.18
21	—.22	.00	—.09	—.08	—.15	.25	.17	.23	.11	—.03	—.06	—.15	—.26	—.28	.17	—.01
22	.32	.46	.30	.31	.50	.43	.28	.33	.52	.23	.22	.32	.43	.39	.30	.23
23	.17	.49	.28	.30	.43	.48	.33	.40	.48	.15	.07	.14	.23	.17	.31	.26
24	.08	.14	.23	.16	.16	.24	.30	.20	.26	.11	.07	.03	.14	.06	.22	.45
25	.32	.16	.17	.12	.07	.21	.09	.11	.01	.27	.23	.12	—.01	.00	.11	.10
26	.28	.26	.20	.16	.21	.17	—.01	.10	—.07	.16	.10	.14	.00	.08	—.02	.15
27	.21	—.02	.01	—.06	—.08	.14	—.03	.00	—.07	.16	.22	.02	—.10	—.08	.10	.15
28	.39	.20	.20	.14	.16	.33	.18	.25	.14	.18	.12	.10	.02	.02	.03	.15
29	—.04	.05	.05	—.01	.11	.27	.21	.28	.23	—.07	—.10	.05	.14	.08	—.01	.05
30	—.06	.22	.24	.20	.15	.14	.16	.17	—.02	.11	—.03	.11	.09	.08	.10	.13
31	—.15	.14	.16	.12	.09	.18	.20	.17	.11	.12	.04	.10	.16	.10	.24	.13
32	.36	.35	.30	.32	.33	.18	.15	.11	.21	.35	.28	.36	.37	.39	.30	.16

TABLE 1 (continuel)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	—.01	.24	.21	—.24	—.22	.34	.21	.08	.34	.33	.19	.37	—.07	—.02	—.15	.38
2	.36	.28	.43	.13	—.02	.43	.44	.14	.20	.27	.01	.17	.06	.17	.11	.40
3	.35	.26	.41	.04	—.07	.32	.29	.25	.13	.22	.01	.23	—.01	.29	.16	.28
4	.29	.24	.39	.03	—.10	.31	.29	.14	.10	.16	—.04	.14	.02	.15	.11	.36
5	.20	.40	.35	.00	—.13	.52	.45	.15	.05	.20	—.09	.15	.10	.17	.10	.34
6	.32	.31	.40	.27	.24	.40	.48	.26	.25	.15	.14	.33	.27	.12	.19	.19
7	.33	.33	.34	.13	.15	.29	.33	.26	.09	.00	—.03	.19	.25	.14	.20	.15
8	.29	.23	.31	.15	.22	.35	.41	.21	.15	.09	.03	.22	.27	.14	.18	.07
9	.21	.60	.25	.06	.11	.55	.49	.26	—.04	—.06	—.08	.15	.26	—.02	.15	.18
10	.30	.18	.36	—.02	—.04	.22	.16	.08	.24	.12	.19	.15	—.08	.09	.16	.32
11	.05	.21	.43	—.07	—.02	.26	.08	.02	.22	.11	.22	.12	—.13	.00	.07	.29
12	.20	.21	.36	—.17	—.16	.35	.16	.06	.10	.09	.05	.14	.03	.13	.10	.35
13	.05	.54	.33	—.14	—.30	.41	.21	.13	.10	.00	—.10	—.06	.20	.10	.11	.33
14	.10	.40	.37	—.17	—.26	.39	.18	.09	.02	.07	—.07	.05	.03	.12	.09	.38
15	.55	.29	.54	.20	.20	.26	.28	.22	.11	—.01	.07	.04	.01	.17	.18	.31
16	.85	.10	.50	.17	—.08	.23	.25	.44	.13	.13	.18	.13	.06	.10	.14	.14
17		.22	.52	.17	.03	.32	.32	.48	.07	.09	.15	.08	.04	.17	.18	.13
18	.19		.34	.03	—.12	.63	.47	.39	.00	—.13	—.06	.10	.09	—.14	.09	.39
19	.55	.34		.17	.01	.42	.38	.33	.12	.11	—.02	.10	.11	.08	.16	.42
20	.20	.01	.10		.51	.02	.39	.07	.22	.13	.25	.19	.06	.05	.13	—.13
21	.01	—.11	—.06	.48		—.05	.24	—.07	.29	.13	.26	.17	—.02	.04	.11	—.21
22	.27	.61	.45	.09	—.05		.83	.21	.05	.15	.00	.19	.16	.08	.14	.46
23	.31	.49	.41	.36	.22	.77		.27	.17	.27	.10	.29	.23	.16	.22	.31
24	.48	.36	.31	.08	—.07	.23	.22		.05	—.04	.10	.11	.03	.14	.22	.20
25	.05	.00	.08	.22	.27	.06	.17	.08		.54	.77	.71	—.05	.11	.01	.12
26	.10	—.13	.07	.13	.08	.16	.25	—.03	.54		.45	.64	.27	.26	.04	.07
27	.10	—.04	.04	.26	.28	—.02	.09	.09	.75	.47		.64	—.08	.00	—.06	—.02
28	.11	.06	.10	.15	.15	.19	.27	.11	.74	.61	.65		.14	.16	—.01	.19
29	.06	.08	.07	.02	—.03	.22	.26	.08	—.04	.22	—.08	.12		.49	.45	.13
30	.16	—.10	.12	.06	.02	.04	.15	.09	.11	.27	.01	.16	.48		.53	.07
31	.19	.11	.20	.13	.10	.13	.23	.19	.02	.04	—.05	.00	.42	.52		.21
32	.21	.38	.36	—.15	—.21	.47	.33	.20	.12	.08	—.01	.15	.07	.11	.14	

TABLE 2

Matrix F_c — The centroid factor loadings, the communalities and the reliabilities of the 32 variables

Var.	Factor											
	I	II	III	IV	V	VI	VII	VIII	IX	X	h^2	r_a
1	.338	.235	−.179	−.351	.104	.191	−.186	−.235	.067	−.182	.499	.98
2	.759	.303	.154	.215	.183	.262	.144	.048	−.193	−.083	.907	.81
3	.729	.313	.113	.277	.281	.165	.106	−.136	−.037	.131	.873	.69
4	.683	.403	.149	.269	.279	.218	.116	−.076	−.159	.095	.902	.88
5	.713	.458	.137	.038	.289	.167	.177	.134	.027	.088	.908	.84
6	.656	−.401	.247	−.071	.220	−.201	−.267	.059	.020	−.141	.841	.77
7	.611	−.292	.409	.038	.399	−.239	−.224	−.126	−.069	−.080	.921	.79
8	.609	−.362	.354	.007	.470	−.219	−.249	.038	−.052	−.073	.968	.81
9	.563	−.148	.417	−.325	.284	−.303	−.271	.139	.022	.092	.893	.91
10	.579	.349	−.193	.286	−.105	.006	−.160	−.107	−.077	−.032	.631	.47
11	.462	.439	−.322	.217	−.280	−.091	−.231	.103	.176	.071	.744	.53
12	.607	.524	−.195	.259	.046	−.168	−.129	.080	.097	−.095	.820	.49
13	.515	.548	−.087	−.128	.043	−.249	.068	.111	.102	.204	.722	.83
14	.552	.665	−.162	.084	.021	−.184	.028	.141	.186	.046	.872	.47
15	.468	−.071	.066	.225	−.487	−.188	−.163	−.080	−.149	−.194	.644	.67
16	.519	−.207	.286	.269	−.257	.147	.122	−.281	.342	−.078	.771	.54
17	.526	−.247	.336	.261	−.367	.079	.137	−.319	.263	−.146	.871	?
18	.494	.179	.265	−.488	−.189	−.193	−.063	.048	.062	.265	.738	.92
19	.623	.066	.162	.107	−.296	−.088	−.009	−.082	.052	−.146	.556	.55
20	.200	−.442	.083	.151	−.185	.221	.013	.351	−.131	.165	.516	.73
21	.086	−.487	−.022	.200	−.083	.108	−.221	.361	−.290	.122	.582	.41
22	.642	.132	.191	−.476	−.180	−.026	.100	.227	−.027	−.209	.832	.94
23	.649	−.168	.199	−.361	−.183	.131	.193	.351	−.215	−.126	.893	.90
24	.367	−.144	.219	−.101	−.215	−.039	.109	−.305	.179	.238	.455	.87
25	.391	−.294	−.579	−.092	−.002	.384	−.283	−.116	−.069	.126	.845	.87
26	.350	−.219	−.480	−.057	.177	.375	.143	.046	.126	−.243	.674	.90
27	.250	−.364	−.520	−.046	−.141	.380	−.295	−.038	.136	.146	.760	.90
28	.442	−.321	−.462	−.236	.154	.355	−.153	−.107	.079	−.036	.760	.89
29	.243	−.269	−.148	−.135	.218	−.394	.447	.116	.077	−.122	.608	.73
30	.292	−.223	−.273	.166	.160	−.219	.514	−.126	−.176	−.044	.624	.84
31	.309	−.217	−.129	.108	−.086	−.404	.412	−.044	−.226	.136	.583	?
32	.463	.279	−.041	−.261	−.164	−.096	.021	−.231	−.149	−.158	.499	.79

h^2 = communalities

r_a = split-half reliabilities augmented by the Spearman-Brown formula for tests twice as long

As previously stated, three centroid factors were defined by the loadings of this table, and an attempt was made to interpret them.

Further Treatment of the Data. In the present study the original table of intercorrelations was factored into ten significant centroid factors shown in Matrix F_c, Table 2. The significance of the number of factors employed is based upon certain criteria developed in Professor Thurstone's laboratory and not yet published. The table also contains the communality of each variable, h^2, i.e., the sum of the squares of the factor loadings for each variable. A comparison of these with the reliability of each measure as reported by Thorndike, which is also given, indicates the extent to which the present study accounts for all the abilities involved in the performance on the various tasks. Thus, as would be expected, the maze behavior is fairly well accounted for. The eighteen measurements enable us to represent maze-performance in a quite comprehensive manner. On the other hand, the performance on the revolving wheel activity cage shows a large discrepancy between the communality and the reliability. Here, then, is exhibited a complex of abilities which, though capable of reliable measurement, has comparatively little in common with the abilities made use of in the performance of the other tasks represented in this study and hence escapes identification.

A comparison of the reported reliabilities and the obtained communalities (see Table 2) indicates that exclusive of the mazes the reliabilities exceed the communalities. But the maze measurements often show a reversal of this condition. This reversal must be interpreted to mean that, contrary to the expectation of Thorndike, these reported reliabilities are too low. This statement is strengthened by an examination of the table of intercorrelations (see Table 1) in which, in twelve out of thirteen cases, the variables in question show one or more raw correlations with some other variable which exceed the reported augmented reliability. In the thirteenth case another intercorrelation equals the reported augmented reliability. On the other hand, the reversal might conceivably mean that the several measurements of the same maze, by being almost duplicates of one another, would give rise to common factors in the error space. In that case the communalities might be too high.

To indicate the extent to which the factorial Matrix F_c, found in Table 2, accounts for the original Matrix R (Table 1 *above* the diagonal), the matrix multiplication FF' has been carried out and the resultant values entered in Table 1, *below* the diagonal. The discrepancies between corresponding entries constitute the tenth factor residuals.

Rotation of Axes. After extracting the ten centroid factors

shown in Table 2, an attempt was made to rotate the reference axes to new positions in which they would conform to the principle of simple structure and positive manifold. Several methods of rotations were made use of; among them, the last one employed, was the method of extended vectors, a method recently devised by Thurstone (**22**). The final position of the reference axes is such that the cosines of the angles made by these new reference axes with the respective centroid reference vectors are those appearing in Table 3. The new reference vectors are tentatively denoted by capital letters, A, B, etc.

Thus Factor *A*, defining one of the hyperplanes, is selected such that it makes an angle of $+16° 44'$ ($\cos^{-1}$ .288) with the first centroid axis, $\cos^{-1}$ .082 with the second, etc.

This new set of reference axes does not define a strictly orthogonal frame. The cosines of the angles which these axes make with one another are given in Table 4, below the diagonal entries. Thirty-one of these (forty-five) cosines indicate that the corresponding angles between reference vectors are more than 87° ($\cos^{-1} = .0523$). Of the six cosines which exceed $\pm.150$, four are descriptive of angles which Factor *D* makes with the other axes; this question will be considered further under the discussion of this axis. It cannot be stated whether or not one or more degrees of freedom would permit this structure to be described in a completely orthogonal frame, but since the maximum departure from orthogonality is 18° 40′, as indicated by a cosine of —.320, it may be said that for purposes of interpretation the factors are orthogonal. The cosines of the angles between the primaries themselves are found in Table 4, above the diagonal entries. This matrix is designated TT' and $TT' = D(\lambda\lambda')^{-1}D$.

Table 3

Matrix λ

Cosines of the angles subtended by the final and the centroid axes

Centroid Axes	Final									
	A	B	C	D	E	F	G	H	J	K
I	.288	.279	.210	.270	.322	.124	.129	.360	.141	.166
II	.082	−.218	−.365	.156	.132	−.283	−.331	.521	−.221	−.048
III	−.163	−.694	.189	.235	.071	−.402	−.044	−.195	.314	.024
IV	.276	−.245	.021	.094	−.680	.115	.299	.514	.202	−.342
V	−.546	.058	.582	.409	−.248	.149	−.287	.211	−.334	.130
VI	−.343	.342	−.427	.253	−.240	−.405	.140	.061	.193	.279
VII	−.309	−.288	−.469	.055	.170	.721	−.024	.036	.268	.212
VIII	−.082	−.330	.054	−.362	.167	−.056	.659	.358	−.332	.474
IX	−.173	.124	.184	−.672	.190	−.132	−.210	.284	.676	.140
X	−.509	.077	−.093	.150	.446	−.057	.449	.196	−.063	−.685

The factor loadings on the new reference axes are given in Table 5. It can be seen that they are, with the exception of variables [1] and [32], on Factor *G*, enclosed within a positive manifold. Other negative factor loadings are so small that they may easily be attributed to chance errors.

Table 4

Entries above diagonal: matrix $TT' = D(\lambda\lambda')^{-1}D$, cosines of angles between the primary factors established

Entries below diagonal: matrix $\lambda\lambda'$, cosines of the angles subtended by the reference vectors of the primary planes with each other

Vector	A	B	C	D	E	F	G	H	J	K
A	1.000	–.015	.058	.259	.259	–.006	.059	.003	.091	.065
B	.014	1.000	–.009	.025	–.044	–.009	.106	.020	.042	.043
C	–.010	.022	1.000	.100	.113	.046	.138	–.021	.160	.009
D	–.179	–.003	–.007	1.000	.261	–.008	.194	–.021	.367	.255
E	–.204	.036	–.101	–.214	1.000	–.016	–.045	.056	.065	.041
F	.001	.007	–.045	.004	.019	1.000	–.005	.000	.026	–.041
G	–.030	–.103	–.115	–.112	.095	.010	1.000	–.250	.213	.137
H	–.005	–.049	–.007	–.006	–.038	–.001	.248	1.000	–.035	–.011
J	.003	–.022	–.116	–.320	.028	–.025	–.135	–.010	1.000	.086
K	–.001	–.026	.022	–.222	.018	.038	–.094	–.018	.020	1.000

Psychological Interpretations of the Factors. In order that a factor may be identified and interpreted within a study such as this, the following conditions must be satisfied:

1. It must possess a number of loadings of sufficient magnitude to identify it unequivocally. Thurstone (**21**) uses loadings of .40 or larger.

2. The loadings should be derived from tasks of sufficient heterogeneity that the investigator may identify the common psychological element as distinct from the mode of measurement. Thus, several factors in the present study, while easily identified as primary factors, cannot be described in terms of psychological principles because they are represented only by performance on one kind of apparatus. For such factors further investigation should be made in order that the loadings obtained on the one task already tested may be compared with loadings on a different task. Such other tasks, though they employ the same ability, should differ sufficiently in mode of measurement (that is, apparatus employed) to enable one to arrive at the common principle by induction. The loadings of the task already measured should remain invariant.

In the interpretation of the factors the reader must keep in mind

Table 5

Matrix F_f = Matrix F_c · Matrix λ
Loadings on rotated factors

Variable	A	B	C	D	E	F	G	H	J	K
1	.084	.450	.027	.146	.155	−.174	−.381	.025	−.044	.211
2	.115	−.001	−.017	.558	.000	.024	.070	.517	.018	.222
3	.002	.081	.083	.555	.033	.045	−.014	.586	.104	−.040
4	.002	.003	.003	.632	−.002	−.002	.002	.588	.000	.004
5	−.099	−.017	.027	.416	.259	−.005	.004	.639	.002	.215
6	.191	.109	.688	.134	.123	.011	.072	−.034	.063	.202
7	.011	−.014	.725	.413	.083	.005	−.006	.020	.037	−.074
8	.028	.001	.810	.325	.026	.025	.027	.027	−.031	.133
9	−.037	−.066	.669	.170	.437	−.140	.016	−.017	−.086	.123
10	.449	.215	−.042	.228	−.025	−.032	.019	.481	−.019	−.109
11	.462	.216	−.104	−.157	.171	−.117	.129	.597	.006	−.112
12	.418	.088	.095	.085	.072	.005	−.055	.695	−.075	.031
13	.082	.005	−.006	.072	.509	.054	−.055	.527	−.126	−.021
14	.239	.011	−.040	.017	.320	.018	−.075	.726	−.061	.046
15	.692	−.007	.001	−.004	.003	−.002	.157	.005	.169	−.070
16	.216	.055	.030	−.001	.010	.004	.005	.102	.739	.013
17	.334	−.004	.003	.001	.010	.034	−.003	−.007	.754	.007
18	.018	−.012	.070	.029	.754	−.173	.013	.001	.033	.005
19	.455	−.002	.028	.056	.172	−.003	.026	.171	.297	.071
20	−.019	−.001	−.006	−.015	.012	.014	.630	−.001	.075	.080
21	.079	.047	.160	.025	−.157	−.024	.630	−.064	−.181	−.012
22	.202	−.008	−.001	.024	.569	−.031	−.005	.015	.027	.505
23	.109	−.006	−.034	.129	.455	.081	.308	−.062	.002	.520
24	.000	.091	.004	.053	.354	.028	−.022	−.093	.432	−.191
25	.072	.850	.015	.103	−.008	.002	.201	.030	−.097	−.007
26	−.026	.572	−.014	−.020	−.098	.264	.015	.146	.073	.440
27	.057	.769	−.010	−.149	.005	−.074	.275	.015	.081	−.012
28	−.034	.788	.140	.063	.059	.071	.019	−.014	.008	.230
29	−.048	−.027	.235	−.122	.220	.655	−.036	−.016	.012	.258
30	.048	.082	.005	.191	−.042	.744	.018	.063	.005	.010
31	.154	−.068	−.005	.103	.187	.636	.188	−.002	−.013	−.161
32	.332	.158	−.107	.204	.290	.036	−.267	−.010	−.035	.086

the direction of the measurements of errors, time consumption, etc., which is given on page 182.

Factor A. Inspection of column *A* in Table 5, reveals that twenty-two variables have projections of between ±.20. Such loadings, contributing only .04 or less to the communality, may be considered as zero entries and will be here-in-after referred to as vanishing projections. Such a vanishing projection has no bearing on the interpreta-

tion of the factor in question. Five variables have loadings in excess of .400. They are:

(10)	"*A* errors" on elevated Maze *C*	+.449
(11)	"*B* errors" on elevated Maze *C*	+.462
(12)	"*C* errors" on elevated Maze *C*	+.418
(15)	"*A* errors" on elevated Maze *D*	+.692
(19)	Time to run elevated Maze *D*	+.455

For the purpose of interpretation these loadings must be considered of major importance. Some minor consideration should also be attributed to measures having projections of between .200 and .400. They are:

(14)	Time to run elevated Maze *C*	+.239
(16)	"*B* errors" on elevated Maze *D*	+.216
(17)	"*C* errors" on elevated Maze *D*	+.334
(32)	Feeding on Preliminaries	+.332

Inspection of the loadings shown above indicates immediately that, except for [32], they are all measures of good performance on the elevated mazes. In other words, animals which possess this ability in more than average degree will make fewer than average errors on these mazes and take less than average time. What abilities or factors will effect such improvements? Honzik (**5**, p. 11) states: "Vision, if it is present, assumes the dominant, almost the exclusive, role in the learning of an elevated maze of the type used." (His maze was not greatly different from Thorndike's elevated Maze *D*.)

A visual factor is therefore indicated; a factor which enables the animal to perceive visual patterns, react to visual cues; a visual-directional ability. This conclusion is further corroborated by the findings of Tsang. (**28**, **29**).

It is a little more difficult to interpret the loading of variable [32] on this factor. One explanation might be that animals which rely predominantly on vision for orientation in the sensory milieu will tend to respond to distracting stimuli visually (that is, merely by looking toward the stimulating object) while continuing to feed; on the other hand, animals which are not so constituted and hence do not rely so much on vision will, when disturbed, leave the food and investigate at closer range by olfaction, vibrissae stimulation, or other taction.

Factor B. Twenty-five variables show vanishing projections on this factor. To be considered significant in explanation of the factor are the following:

(1)	Turns of the activity cage	+.450
(25)	Number of jumps in response to the buzzer signal in "C.R." apparatus	+.850

(26)	Number of jumps between buzzer signals	+.572
(27)	Number of jumps in response to the light signal in "C.R." apparatus	+.769
(28)	Number of jumps between light signals	+.788

Smaller loadings (probably insignificant) are:

(10)	"*A* errors" on elevated Maze *C*	+.215
(11)	"*B* errors" on elevated Maze *C*	+.216

The loadings indicated above are primarily those of the "conditioned response" apparatus. A reading of the report of Warner's original experiment and also of Thorndike's repetition of it leads one to believe that very little "conditioning" takes place in many animals. Those experienced in handling rats know of their "explosive" and purposeless behavior when shocked. This common observation, together with the fact that loadings on [26] and [28] are, for all practical purposes, as large as those on [25] and [27], leads one to doubt that any appreciable association of the signal with the shock is established. This factor, which is indicated by the above loadings, appears, then, to be a measure of wildness or panicky behavior, a measure of activities which are the results of fear.

Interestingly enough, Vaughn (**30**) identified a wildness-timidity trait in his study, even though his factor does not appear to be so clear-cut.

This fear may also cause the animal to avoid "*A*" and "*B*" errors on the first elevated maze by intensifying its attention to the available cues.

This explanation fits in nicely with interpretation of [1] included in this factor. Dr. Lashley told this writer that wild trapped animals, when put into an activity cage, must be watched carefully lest they "run themselves to death."

Factor C. Twenty-seven of the variables have vanishing projections on this factor. The significant ones are:

(6)	"*A* errors" in alley Maze *B*	+.688
(7)	"*B* errors" in alley Maze *B*	+.725
(8)	"*C* errors" in alley Maze *B*	+.810
(9)	Time to run alley Maze *B*	+.669

A small loading which might or might not be significant is

(29)	Number of approaches to the grid in the Columbia Obstruction Apparatus	+.235

This writer is at a loss to attempt any psychological interpretation of this factor. Honzik's (**5**) study shows that when an animal is deprived of vision and is faced with a problem normally solved by the aid of vision, it first falls back on olfaction for sensory cues. Factor *C* might represent an olfactory factor. Thorndike's report does not indicate that there were any controls to eliminate it.

On the other hand, the factor might have to be interpreted in terms of an ability displayed by the animal when faced with a double alternating alley maze. It should be remembered that Hunter (**8**) found that the animals had great difficulty solving this principle as such.

Factor D. This one is the *bête noire* of the factors. As it stands, twenty-four of the variables have vanishing projections on it. The variables which unquestionably have high loadings on it are:

(2)	"*A* errors" in alley Maze *A*	+.588
(3)	"*B* errors" in alley Maze *A*	+.555
(4)	"*C* errors" in alley Maze *A*	+.632
(5)	Time to run alley Maze *A*	+.416
(7)	"*B* errors" in alley Maze *B*	+.413

Some other and smaller loadings which may help in interpreting are:

(6)	"*A* errors" in alley Maze *B*	+.134
(8)	"*C* errors" in alley Maze *B*	+.325
(9)	Time to run alley Maze *B*	+.170
(10)	"*A* errors" on elevated Maze *C*	+.228
(32)	Feeding on Preliminaries	+.204

As the configuration is thus described the hyperplane defining zero loadings on Factor *D* has a number of large negative cosines with the other reference axes. These negative cosines mean that the hyperplane described is turned up into the positive manifold. If the cosines were reduced by turning this hyperplane away from *J* and *A*, the variables with significant loadings on these factors would also take a considerable loading on *D*. In turn, this would mean that *all* the error scores on all four mazes would take on some loading. The objectionable feature is that it would leave a configuration which was rather ill-defined. After inspection of both alternatives, the first-mentioned one was selected. This choice allows the variables having loadings on Factor *C* to take on loadings on *D* also, but excludes the ones on *A* and *J*.

Inspection of the variables having significant loadings on this factor discloses that they are all temporally located at the beginning of the experimental routine and that these loadings decrease progressively as time goes on and as the animals accustom themselves to their

environment. The animals which possess this ability adapt relatively quickly to new situations and, by so doing, are able to bring other abilities into play, thereby making comparatively few errors at the beginning of the experimental period. Such a factor is probably of an emotional rather than a cognitive nature and would be closely allied to the general progressive adaptation so prominently mentioned by Jackson (**10**) and by Alm (**1**). It has a counterpart in humans which is implied when we speak of children as having become "test wise." If the scores had been made by human subjects, this factor might have been termed "self-confidence."

The manifestation of this factor is probably the one which caused Tolman and Nyswander (**24**) to postulate that retracing was due to nervousness and caution, and the fact that [7] and [8] have significant loadings, whereas [6] and [9] do not, fits in with this line of reasoning.

Factor E. Twenty-two variables have very small or no loadings on this factor. Those to be considered are:

(5)	Time to run alley Maze *A*	+.259
(9)	Time to run alley Maze *B*	+.437
(13)	Time to start running elevated Maze *C*	+.509
(14)	Time to run elevated Maze *C*	+.320
(18)	Time to start running elevated Maze *D*	+.754
(22)	Time to start running in Jenkins Circular Problem Box	+.569
(23)	Time to run Jenkins Circular Problem Box	+.455
(24)	Time to reach food compartment in Latch Box Problem	+.354
(32)	Feeding on Preliminaries	+.290

All the above measurements are of time consumed to do some task. Animals possessing this factor in a more than average degree will take less than average time to perform the above tasks.

Some smaller loadings on this factor are:

(19)	Time to run elevated Maze *D*	+.172
(29)	Number of approaches to grid in Columbia Obstruction Apparatus	+.220

The ability indicated may be called a "speed factor" as Vaughn (**30**) termed it, but this name does not seem to do justice to the concept even though its end product is not incommensurable with speedy action. Possibly underlying the behavior measured here is a differential of motility of an innate character. Leeper (**14**) and

Rundquist (**18**) have shown that there is a hereditary aspect about this difference in rate of auto-kinesis.

This factor has been anticipated or surmised by a number of investigators. Time measurements have been subject to published speculation by, among others, Hicks (**4**), Hubbert (**7**), Davis and Tolman (**3**), Tolman and Nyswander (**24**), for animal learning, as well as Husband (**9**), Snoddy (**19**), Tinker (**23**) and Tryon (**26**), for human learning.

It should be noted that with the exception of variable [18], each one of these measures shows significant loadings on at least one other factor; that is, time scores reflect speediness of the animal together with the time consumed in making various kinds of errors. Both of these have been partialed out in the present study. Time scores were analyzed by partial correlation technique by Tolman and Nyswander (**24**). Their conclusion, based on an incomplete realization of the principles involved, was that time scores were ambiguous and should not be used. The present study indicates that, while raw time scores are ambiguous, they are no more so than raw error scores if these also have loadings on several factors.

Factor F. Twenty-eight variables have insignificant loadings on this factor. The significant ones are all connected with the Columbia Obstruction Apparatus.

(29)	Number of approaches to the grid	+.655
(30)	Number of contacts with the grid (resulting in shock)	+.744
(31)	Number of complete crossings of grid	+.636

A smaller loading is found on

(26)	Number of crossings between the buzzer signals in the Conditioned Response Apparatus	+.264

It is difficult to make psychological interpretations of such loadings, but, so far as this battery is concerned, the factor seems to be specific to the Columbia Obstruction Apparatus. The apparatus was designed to measure strength of drive under punishment, and this interpretation is possibly as close as the factor can be defined at present.

Factor G. Twenty-five variables have none of their variance to be accounted for by this factor. Those which have large loadings are:

(20)	Number of quadrants entered in Jenkins Circular Problem Box	+.630
(21)	Perfect trials in the Jenkins Circular Problem Box	+.630
(1)	Number of turns on Revolving Wheel Activity Cage	—.381

Other smaller loadings are:

(23)	Time to run Jenkins Circular Problem Box	+.308
(25)	Crossings to the buzzer in Conditioned Response Apparatus	+.201
(27)	Crossings to the light in above apparatus	+.275
(32)	Feeding on Preliminaries	—.267

In this case, also, psychological interpretation must be made with care. Strictly speaking, all that can be said about this factor is that it is specific to the Jenkins Circular Problem Box; yet the writer deems it important that this factor also splits the scores on the Conditioned Response Apparatus in such a way that the scores which indicate understanding of problems [25] and [27] have loadings, whereas the other scores on this same piece of apparatus (but indicating only erratic and random behavior under the stimulation of fear) have no loadings at all. This factor appears to indicate the extent to which specific association between signal and response was established.

This factor is also the only one in which a significant negative loading (on variable [1]), is observed.

What, then, shall we say of animals which: (1) enter few quadrants, have many perfect trials and take short time in the Jenkins Box; (2) make relatively few turns on the activity cage; (3) within the limited training time on the Conditioned Response Apparatus, learn to cross at the right time? They seem to display some kind of a cognitive, possibly a logical, factor, a generalized problem-solving ability and perhaps an alertness to sensory cues. The presence of [32] in negative form cannot be explained by this writer; it might be fortuitous.

Factor H. Twenty-three variables have vanishing loadings on this factor. Nine variables have significant loadings. They are:

(2)	"*A* errors" in alley Maze *A*	+.517
(3)	"*B* errors" in alley Maze *A*	+.586
(4)	"*C* errors" in Alley Maze *A*	+.588
(5)	Time to run Alley Maze *A*	+.639
(10)	"*A* errors" on elevated Maze *C*	+.481
(11)	"*B* errors" on elevated Maze *C*	+.597
(12)	"*C* errors" on elevated Maze *C*	+.695
(13)	Time to start on elevated Maze *C*	+.527
(14)	Time to run on elevated Maze *C*	+.726

Obviously, the common element in this case is the principle of turning alternately right and left. The discovery of this working principle seems well within the grasp of the animals. An "alternating hypothesis" was described by Krechevsky (**11**). Miles (**17**) has

shown that the principles or factors used in the alley maze are also made use of in the elevated maze and vice versa.

Factor J. Twenty-eight variables have vanishing projections on this factor. Only three variables have loadings above .400, and one has a loading of about .300. The variables with significant loadings are:

(16)	"*B* errors" on elevated Maze *D*	+.739
(17)	"*C* errors" on elevated Maze *D*	+.754
(24)	Time to reach food in Latch Box	+.432

Another fairly high loading is

(19)	Time to run elevated Maze *D*	+.297

It is difficult to differentiate this factor from *A*. Both appear to involve vision. Yet *J* is independent of *A*. Dr. Thorndike told the writer that "*B*" and "*C*" errors on the *D* Maze were relatively rare. The most plausible interpretation seems to point to "relationships visually perceived," perhaps a "visual insight" factor, as distinct from *A*, which seems to operate as a "visually directing" factor at choice points. Honzik's data (**5**) on the function of vision in maze learning, and Honzik and Tolman's data (**6**) on the role of vision in spatial relationship, both indicate that more than one factor enters into the observed behavior. One of these, *A*, may be tentatively thought of as an ability to benefit from sensory cues at the various choice points, while the other, *J*, may be thought of as a visual perception of the total maze gestalt.

Factor K. The hyperplane defining absence and presence of significant loadings on this factor is not very well determined. It may be that this factor is contaminated by factors not extracted. There are twenty-three variables having negligible loadings. On the other hand, only three variables have loadings in excess of .400. They are:

(22)	Time to start running in the Jenkins Circular Problem Box	+.505
(23)	Time to run above-mentioned apparatus	+.520
(26)	Number of crossings between buzzer signals in Conditioned Response Apparatus	+.440

This leaves six variables having loadings between .200 and .300. They are:

(1)	Number of turns in activity cage	+.211
(2)	"*A* errors" in alley Maze *A*	+.222
(5)	Time to run alley Maze *A*	+.215
(6)	"*A* errors" in alley Maze *B*	+.202

(28)	Number of crossings between light signals in Conditioned Response Apparatus	+.230
(29)	Number of approaches to the grid in Columbia Obstruction Apparatus	+.258

This is probably a residual factor as it stands, and no attempt will be made to interpret it psychologically even though there seems to be some consistency in the loadings.

Factors and Apparatus. A survey of the battery in terms of the concomitance of primary abilities and the apparatus employed as measurement will be attempted. It would seem pertinent to think of this when selecting apparatus for further research.

The activity wheel cage, as has been stated, is a reliable measuring instrument, but, except for loadings on *B* (tendency toward panic) and *G* (cognitive?) factors, the behavior exhibited in this apparatus is not sufficiently like that measured by other tests in the battery to be distinctly analyzed. Much of the variance remains to be accounted for.

The Warner-Warden single alternating maze involves two factors previously described, the *D* (general adaptation or confidence) and the *H* (single alternation principle) factors. The time measurement reflects both these factors and, in addition, the general motility factor, *E*.

The Warner-Warden double alternating maze yields scores which define a Factor *C*. This appears to be specific to this apparatus in so far as this battery is concerned. The time measurements behave as indicated above.

The elevated mazes seem to be primarily solved by the visually-directing ability, Factor *A*. If the maze also involves a single alternating principle, Factor *H* also may be involved. Apparently a high degree of familiarity with elevated mazes leads to a shift from behavior depending upon visual orientation at each choice point to an insight in terms of the total visual gestalt (Factor *J*).

The Jenkins Circular Problem Box has a factor specific to it in so far as this battery is concerned. A guess might be made that this is some cognitive factor, but such a guess is based on inadequate loadings.

The Latch Box presents a dilemma similar to that of the Activity Cage. The large difference between the communality and the reliability indicates that the ability to solve this problem is not utilized in other tasks represented in the battery. There is a loading on the visually-perceptive Factor *J*, but it accounts for only a small portion of the total variance of this test.

It turns out that the so-called Conditioned Response Apparatus measures principally a tendency for hyperactivity under fear. This is probably the same factor generally referred to as wildness. There are some slight loadings of the relevant responses on a factor tentatively identified as cognition, *G*.

The Columbia Obstruction Apparatus employs a factor which in the battery under consideration is specific to this piece of apparatus.

The writer has lithoprinted copies of the 45 plots (each factor with every other one), together with a plot of the tenth factor residuals. They may be obtained on request.

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